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Entry into National Phase
PCT/EP2004/013447
LTF-206

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Priority: Germany (DE) December 23, 2003 No. 103 60 962.8

10/584483
IAP2 Rec'd PCT/PTO 23 JUN 2006

Method for quadrature-bias compensation in a Coriolis gyro, as well as a Coriolis gyro which is suitable for this purpose

The invention relates to a method for quadrature-bias compensation in a Coriolis gyro, and to a Coriolis gyro which is suitable for this purpose.

Coriolis gyros (also referred to as vibration gyros) are being increasingly used for navigation purposes; they have a mass system which is caused to oscillate. Each mass system generally has a large number of oscillation modes, which are initially independent of one another. In order to operate the Coriolis gyro, a specific oscillation mode of the mass system is artificially excited, and this is referred to in the following text as the "excitation oscillation". When the Coriolis gyro is rotated, Coriolis forces occur which draw energy from the excitation oscillation of the mass system and thus transmit a further oscillation mode of the mass system, which is referred to in the following text as the "read oscillation". In order to determine rotations of the Coriolis gyro, the read oscillation is tapped off and a corresponding read signal is investigated to determine whether any changes have occurred in the amplitude of the read oscillation which represent a measure of the rotation of the Coriolis gyro. Coriolis gyros may be in the form of both an open-loop system and a closed-loop system. In a closed-loop system, the amplitude of the read oscillation is continuously reset to a fixed value - preferably zero - via respective control loops, and the resetting forces are measured.

The mass system of the Coriolis gyro (which is also referred to in the following text as the "resonator") may in this case be designed in widely differing ways. For example, it is possible to use an integral mass system. Alternatively, it is possible to split the mass

system into two oscillators, which are coupled to one another via a spring system and can carry out relative movements with respect to one another. For example, it is known for a coupled system comprising two linear oscillators to be used, and this is also referred to as a linear double-oscillator system. If a coupled system such as this is used, then alignment errors of the two oscillators with respect to one another are unavoidable, because of manufacturing tolerances. The alignment errors of the two oscillators with respect to one another produce a zero error component in the measured rotation rate signal, the so-called "quadrature bias" (or to be more precise: a quadrature-bias component).

The object on which the invention is based is to specify a method and a Coriolis gyro by means of which it is possible to compensate for a quadrature-bias component such as this.

According to the invention, this object is achieved by a method for quadrature-bias compensation for a resonator having two linear oscillators as claimed in patent claim 1. The invention also provides an embodiment of a Coriolis gyro which is suitable for this purpose, as claimed in patent claim 6. A further suitable embodiment of a Coriolis gyro is contained in patent claim 12. Advantageous refinements and developments of the idea of the invention can be found in the respective dependent claims.

In order to assist understanding of the technical background of the method according to the invention, the physical principles of a Coriolis gyro will be explained briefly once again in the following description, with reference to the example of a linear double-oscillator system.

The Coriolis force can be represented as:

$$\vec{F} = 2m\vec{v}_s x\vec{\Omega} \qquad [1]$$

$\vec{F}$ *Coriolis force*

m *Mass of the oscillator*

$\vec{v}_s$ *Velocity of the oscillator*

$\vec{\Omega}$ *Rotation rate*

If the mass which reacts to the Coriolis force is equal to the oscillating mass, and if the oscillator is operated at the natural frequency □, then:

$$2m\vec{v}_s x\vec{\Omega} = m\vec{a}_c \qquad [2]$$

The oscillator velocity is given by:

$$\vec{v}_s = \vec{v}_{s0} \sin \omega t \qquad [3]$$

where

$\vec{v}_{s0}$ *oscillator amplitude*

ω *natural frequency of the oscillator*

The oscillator and Coriolis accelerations are thus given by:

$$\vec{a}_s = \vec{v}_{s0}\omega \cos \omega t$$
$$\vec{a}_s = 2\vec{v}_{s0} \sin \omega t \times \vec{\Omega} \qquad [4]$$

The two acceleration vectors are thus spatially at right angles to one another and are offset through 90° with respect to one another in the time function (spatial and time orthogonality).

These two criteria can be used in order to separate the oscillator acceleration $\vec{a}_s$ from the Coriolis acceleration $\vec{a}_c$. The ratio of the above mentioned acceleration amplitudes a_c and a_s is:

$$\frac{a_c}{a_s} = \frac{2\omega}{\omega} \qquad (5)$$

If the rotation rate is $\Omega = 5°/h$ and the natural frequency of the oscillator is $f_s = 10$ KHz, then:

$$\frac{a_c}{a_s} = 7.7 \cdot 10^{-10} \qquad (6)$$

For an accuracy of 5°/h, undesirable couplings of the first oscillator to the second oscillator must not exceed $7.7 \cdot 10^{-10}$, or must be constant at this value. If a mass system composed of two linear oscillators is used, which are coupled to one another via spring elements, then the accuracy of the spatial orthogonality is limited because of the alignment error of the spring elements between the oscillation mode and the measurement mode. The achievable accuracy (limited by manufacturing tolerances) is 10^{-3} to 10^{-4}. The accuracy of the time orthogonality is limited by the phase accuracy of the electronics at, for example, 10 KHz, which can likewise be complied with only to at most 10^{-3} to 10^{-4}. This means that the ratio of the accelerations as defined above cannot be satisfied.

Realistically, the resultant error in the measured acceleration ratio a_c/a_s is:

$$\frac{a_c}{a_s} = 10^{-6}\ to\ 10^{-8} \qquad (7)$$

The spatial error results in a so-called quadrature bias B_Q, which, together with the time phase error □□, results in a bias B:

$$\begin{aligned} &B_Q = 6.5 \cdot 10^{6}°/h \text{ to } 6.5 \cdot 10^{5}°/h \\ &□□ = 10^{-3} \text{ to } 10^{-4} \qquad (8) \\ &B = B_Q \cdot □□ = 6{,}500°/h \text{ to } 65°/h \end{aligned}$$

The quadrature bias thus results in a major restriction of the measurement accuracy. In this case, it should be

noted that the above error analysis takes account only of the direct coupling of the oscillation mode to the read mode. Further quadrature-bias components also exist and occur, for example, as a result of couplings with other oscillation modes.

The method according to the invention for quadrature-bias compensation can be applied, in particular, to Coriolis gyros whose resonators are in the form of coupled systems comprising at least one first and one second linear oscillator, and has the following steps:

- determination of the quadrature bias of the oscillator system,
- production of an electrostatic field in order to vary the mutual alignment of the two oscillators with respect to one another, with the alignment/strength of the electrostatic field being regulated such that the determined quadrature bias is as small as possible.

The total quadrature bias of the oscillator system is preferably determined in this case. This is preferably done by demodulation of a read signal, which is produced by means of read electrodes, with 0° and appropriate resetting. Alternatively, it is possible to deliberately determine only a portion of the quadrature bias, which is produced by the alignment error of the two linear oscillators with respect to one another. The expression "quadrature bias" covers both alternatives.

The quadrature bias is thus eliminated at its point of origin itself, that is to say mechanical alignment errors of the two oscillators with respect to one another are compensated for by means of an electrostatic force which acts on one or both oscillators and is produced by the electrostatic field.

In one preferred embodiment, the Coriolis gyro has first and second spring elements, with the first oscillator being connected by means of the first spring elements to a gyro frame of the Coriolis gyro, and the second oscillator being connected by means of the second spring elements to the first oscillator. The electrostatic field in this case results in a change in the alignment of the first spring elements and/or a change in the alignment of the second spring elements. The alignment of the second spring elements is preferably varied by varying the position/alignment of the second oscillator by means of the electrostatic field. Analogously to this, the alignment of the first spring elements is preferably varied by varying the position/alignment of the first oscillator by means of the electrostatic field. The change in the positions/alignments of the oscillators in this case results in bending of the spring elements which are attached to the oscillators, thus making it possible to correct corresponding alignment angles of the first spring elements with respect to the second spring elements.

In one particularly preferred embodiment, the electrical field is used to vary the alignment angles of the first and second spring elements such that the alignments of the first and second spring elements are made orthogonal with respect to one another. Once they have been made orthogonal in this way, this compensates for the quadrature-bias (component) that is produced in this way. If there are any further contributions to the quadrature bias, the angle error with respect to orthogonality is adjusted such that the total quadrature bias disappears. The alignment angles of the second spring elements with respect to the first oscillator are preferably varied by means of the electrostatic field, and the alignment angles of the first spring elements with respect to the gyro frame of the Coriolis gyro are not changed. However, it is also

possible to use the electrostatic field to vary only the alignment angles of the first spring elements, or to vary the alignment angles of both the first and the second spring elements.

The method according to the invention furthermore provides a Coriolis gyro whose resonator is in the form of a coupled system comprising at least one first and one second linear oscillator, and which has

- a device for production of an electrostatic field by means of which the alignment of the two oscillators with respect to one another can be varied,
- a device for determination of any quadrature bias which is caused by alignment errors of the two oscillators with respect to one another and further coupling mechanisms, and
- a control loop, with the control loop regulating the strength of the electrostatic field as a function of the determined quadrature bias such that the determined quadrature bias is as small as possible.

If the resonator comprises a first and a second linear oscillator, then the Coriolis gyro preferably has first and second spring elements, with the first spring elements connecting the first oscillator to the gyro frame of the Coriolis gyro, and the second spring elements connecting the second oscillator to the first oscillator. The alignments of the first and second spring elements are in this case preferably at right angles to one another. The spring elements may in this case be of any desired form.

It has been found to be advantageous for the second oscillator to be attached to or clamped in on the first oscillator "at one end". "Clamped in at one end" can in this case be understood not only in the sense of the

literal wording but also in a general sense. In general, attached or clamped in "at one end" means that the force is introduced from the first oscillator to the second oscillator essentially from one "side" of the first oscillator. If, by way of example, the oscillator system were to be designed in such a way that the second oscillator is bordered by the first oscillator and is connected to it by means of second spring elements, then the expression "clamped in or attached at one end" would imply the following: the second oscillator is readjusted for the movement of the first oscillator, with the first oscillator alternately "pushing" or "pulling" the second oscillator by means of the second spring elements. Clamping the second oscillator in at one end on the first oscillator has the advantage that, when an electrostatic force is exerted on the second oscillator as a result of the alignment/position change of the second oscillator which results from this, the second spring elements can be slightly curved, thus making it possible, without any problems, to vary the corresponding alignment angle of the second spring elements. If the second oscillator in this example were to be attached to additional second spring elements in such a way that, during movement of the first oscillator, the second oscillator were at the same time to be "pulled" and "pushed" by the second spring element, then this would be equivalent to the second oscillator being clamped in or attached "at two ends" to the first oscillator (with the force being introduced to the second oscillator from two opposite ends of the first oscillator). In this case, the additional second spring elements would produce corresponding opposing forces when an electrostatic field is applied, so that changes in the alignment angles of the second spring elements could be achieved only with difficulty. However, clamping in at two ends is acceptable when the additional second spring elements are designed such that the influence of these spring elements is small so that all of the

spring elements can bend without any problems in this case as well, that is to say the clamping in is effectively at one end. Depending on the design of the oscillator structure, clamping in at one end can effectively be provided just by the "influence" (force introduction) of the additional second spring elements being 40% or less. However, this value does not present any restriction to the invention, and it is also feasible for the influence of the second spring elements to be more than 40%. By way of example, clamping in at one end can be achieved by all of the second spring elements which connect the second oscillator to the first oscillator being arranged parallel and on the same plane as one another. All start and end points of the second spring elements are in each case attached to the same ends of the first and second oscillator. The start and end points of the second spring elements may in this case advantageously each be on a common axis, with the axes of the second spring elements intersecting at right angles.

If the second oscillator is attached to or clamped in on the first oscillator at one end, then the first spring elements are preferably designed such that they clamp the first oscillator in on the gyro frame at two ends (the expressions "at one end" and "at two ends" can be used analogously here). As an alternative to this, however, it is possible for the first spring elements also to be designed in such a way that they clamp in on the first oscillator at one end. By way of example, all of the first spring elements which connect the first oscillator to the gyro frame of the Coriolis gyro can be arranged parallel and on the same plane as one another, with the start and end points of the first spring elements in each case preferably being located on a common axis. It is equally possible for the spring elements to be designed in such a way that the first oscillator is clamped in on the gyro frame at one end, and the second oscillator is clamped in at two ends by

the first oscillator. It is also possible for both oscillators to be clamped in at two ends. For quadrature-bias compensation, it has been found to be advantageous for at least one of the two oscillators to be clamped in at one end.

A further advantageous embodiment of a Coriolis gyro according to the invention has a first and a second resonator, which are each in the form of a coupled system comprising a first and a second linear oscillator, with the first resonator being mechanically/electrostatically connected/coupled to the second resonator such that the two resonators can be caused to oscillate in antiphase with respect to one another along a common oscillation axis.

This embodiment accordingly has a mass system which comprises two double-oscillator systems (that is to say two resonators) or four linear oscillators. The antiphase oscillation of the two resonators with respect to one another in this case results in the center of gravity of the mass system remaining unchanged, provided that the two resonators are appropriately designed. This means that the oscillation of the mass system cannot produce any external vibration which would in turn result in disturbances in the form of damping/reflections. Furthermore, external vibrations and accelerations in the direction of the common oscillation axis have no influence on the antiphase movement of the two resonators along the common oscillation axis.

By way of example, the first resonator can be coupled to the second resonator via a spring system which connects the first resonator to the second resonator. A further option is for the first resonator to be coupled to the second resonator via an electrostatic field. Both couplings can be used on their own or in conjunction. It is sufficient for the two resonators to

be formed in a common substrate, so that the mechanical coupling is provided by a mechanical spring connection which is formed by the common substrate itself.

In this embodiment as well, the Coriolis gyro advantageously has a device for production of electrostatic fields, by means of which the alignment of the linear oscillators with respect to one another can be varied, a device for determination of the quadrature bias of the Coriolis gyro, and control loops by means of which the strengths of the electrostatic fields are regulated such that the determined quadrature bias is as small as possible.

The configurations of the first and of the second resonator are preferably identical. In this case, the two resonators are advantageously arranged axially symmetrically with respect to one another with respect to an axis of symmetry which is at right angles to the common oscillation axis, that is to say the first resonator is mapped by the axis of symmetry onto the second resonator.

The invention will be explained in more detail in the following text, using an exemplary embodiment, and with reference to the accompanying figures, in which:

Figure 1 shows an outline sketch of a mass system according to the invention which comprises two linear oscillators, with corresponding control loops which are used for excitation of the first oscillator.

Figure 2 shows an outline sketch of a mass system according to the invention which comprises two linear oscillators, with corresponding measurement loops and control loops for a rotation rate Ω and a quadrature bias B_Q, as

well as the auxiliary control loops in order to compensate for the quadrature bias B_Q.

Figure 3 shows an outline sketch of a mass system according to the invention, which comprises four linear oscillators, with corresponding measurement and control loops for a rotation rate Ω and a quadrature bias B_Q, as well as the auxiliary control loops in order to compensate for the quadrature bias B_Q.

Figure 4 shows an outline sketch of one preferred embodiment of the control module shown in Figure 3.

Figure 1 shows the schematic design of a linear double oscillator 1 with corresponding electrodes, as well as a block diagram of associated evaluation/excitation electronics 2. The linear double oscillator 1 is preferably produced by means of etching processes from a silicon wafer, and has a first linear oscillator 3, a second linear oscillator 4, first spring elements 5_1 to 5_4, second spring elements 6_1 and 6_2 as well as parts of an intermediate frame 7_1 and 7_2 and of a gyro frame 7_3 and 7_4. The second oscillator 4 is mounted within the first oscillator 3 such that it can oscillate, and is connected to it via the second spring elements 6_1, 6_2. The first oscillator 3 is connected to the gyro frame 7_3, 7_4 by means of the first spring elements 5_1 to 5_4 and the intermediate frame 7_1, 7_2.

Furthermore, first excitation electrodes 8_1 to 8_4, first read electrodes 9_1 to 9_4, second excitation electrodes 10_1 to 10_4, and second read electrodes 11_1 and 11_2 are provided. All of the electrodes are mechanically connected to the gyro frame, but are electrically isolated. The expression "gyro frame" means a mechanical, non-oscillating structure in which the

oscillators are "embedded", for example the non-oscillating part of the silicon wafer.

If the first oscillator 3 is excited by means of the first excitation electrodes 8_1 to 8_4 to oscillate in the X1 direction, then this movement is transmitted through the second spring elements 6_1, 6_2 to the second oscillator 4 (alternately "pulling" and "pushing"). The vertical alignment of the first spring elements 5_1 to 5_4 prevents the first oscillator 3 from moving in the X2 direction. However, a vertical oscillation can be carried out by the second oscillator 4 as a result of the horizontal alignment of the second spring elements 6_1, 6_2. When corresponding Coriolis forces accordingly occur, then the second oscillator 4 is excited to oscillate in the X2 direction.

A read signal which is read from the first read electrodes 9_1 to 9_4 and is proportional to the X1 movement of the first oscillator 3 is supplied via appropriate amplifier elements 21, 22 and 23 to an analog/digital converter 24. An appropriately digitized output signal from the analog/digital converter 24 is demodulated not only by a first demodulator 25 but also by a second demodulator 26 to form corresponding output signals, with the two demodulators operating with an offset of 90° with respect to one another. The output signal from the first demodulator 25 is supplied to a first regulator 27 in order to regulate the frequency of the excitation oscillation (the oscillation of the mass system 1 in the X1 direction), whose output signal controls a frequency generator 30 such that the signal which occurs downstream from the demodulator 25 is regulated at zero. Analogously to this, the output signal from the second demodulator 26 is regulated at a constant value, which is predetermined by the electronics component 29. A second regulator 31 ensures that the amplitude of the excitation oscillation is regulated. The output signals from the frequency

generator 30 and from the amplitude regulator 31 are multiplied by one another, by means of a multiplier 32. An output signal from the multiplier 32, which is proportional to the force to be applied to the first excitation electrodes 8_1 to 8_4 acts not only on a first force/voltage converter 33 but also on a second force/voltage converter 34, which use the digital force signal to produce digital voltage signals. The digital output signals from the force/voltage converters 33, 34 are converted via a first and a second digital/analog converter 35, 36 to corresponding analog voltage signals, which are then passed to the first excitation electrodes 8_1 to 8_4. The first regulator 27 and the second regulator 31 readjust the natural frequency of the first oscillator 3, and set the amplitude of the excitation oscillation to a specific, predeterminable value.

When Coriolis forces occur, the movement of the second oscillator 4 in the X2 direction (read oscillation) that results from this is detected by the second read electrodes 11_1, 11_2, and a read signal which is proportional to the movement of the read oscillation in the X2 direction is supplied via appropriate amplifier elements 40, 41 and 42 to an analog/digital converter 43 (see Figure 2). A digital output signal from the analog/digital converter 43 is demodulated by a third demodulator 44 in phase with the direct-bias signal, and is demodulated by a fourth demodulator 45, offset through 90°. A corresponding output signal from the first demodulator 44 is applied to a third regulator 46, whose output signal is a compensation signal and corresponds to the rotation rate Ω to be measured. An output signal from the fourth demodulator 45 is applied to a fourth regulator 47, whose output signal is a compensation signal and is proportional to the quadrature bias to be compensated for. The output signal from the third regulator is modulated by means of a first modulator 48, and the output signal from the

fourth regulator 47 is modulated in an analogous manner to this by means of a second modulator 49, so that amplitude-regulated signals are produced whose frequencies correspond to the natural frequency of the oscillation in the X1 direction (sin ^= 0°, cos ^= 90°). Corresponding output signals from the modulators 48, 49 are added in an addition stage 50, whose output signal is supplied both to a third force/voltage converter 51 and to a fourth force/voltage converter 52. The corresponding output signals for the force/voltage converters 51, 52 are supplied to digital/analog converters 53, 54, whose analog output signals are applied to the second excitation electrodes 10_2 to 10_3, and reset to the oscillation amplitudes of the second oscillator 4.

The electrostatic field which is produced by the second excitation electrodes 10_1 and 10_4 (or the two electrostatic fields which are produced by the electrode pairs 10_1, 10_3 and 10_2, 10_4) results in an alignment/position change of the second oscillator 4 in the X2 direction, and thus in a change in the alignments of the second spring elements 6_1 to 6_2. The fourth regulator 47 regulates the signal which is applied to the second excitation electrodes 10_1 and 10_4 in such a way that the quadrature bias which is included in the compensation signal of the fourth regulator 47 is as small as possible, or disappears. A fifth regulator 55, a fifth and a sixth/voltage converter 56, 57 and two analog/digital converters 58, 59 are used for this purpose.

The output signal from the fourth regulator 47, which is a measure of the quadrature bias, is supplied to the fifth regulator 55, which regulates the electrostatic field that is produced by the two excitation electrodes 10_1 and 10_4 in such a way that the quadrature bias B_Q disappears. For this purpose, an output signal from the fifth regulator 55 is in each case supplied to the

fifth and sixth force/voltage converters 56, 57, which use the digital force output signal from the fifth regulator to produce digital voltage signals. These are then converted to analog voltage signals in the analog/digital converters 58, 59. The analog output signal from the analog/digital converter 58 is supplied to the second excitation electrode 10_1 or alternatively 11_1. The analog output signal from the analog/digital converter 59 is supplied to the second excitation electrode 10_4, or alternatively 11_2.

The second oscillator 4 is clamped in only by the second spring elements 6_1 to 6_2 (clamping in at one end), the alignment of these spring elements can be varied without any problems by the electrostatic field. It is also possible to provide additional second spring elements, which result in the second oscillator 4 being clamped in at two ends, provided that these additional spring elements are designed appropriately to ensure that clamping in at one end is effectively achieved. In order to allow the same effect for the spring elements 5_1, 5_2 and the spring elements 5_3, 5_4 as well, the third and fourth spring elements 5_3, 5_4 and the first and second spring elements 5_1, 5_2 may be omitted, thus resulting in the first oscillator 3 being clamped in at one end (together with an appropriately modified electrode configuration, which is not shown here). In a situation such as this, the second oscillator 4 can also be attached to the first oscillator by means of further spring elements in order to achieve clamping in at two ends.

The electrode arrangements which are shown in Figures 1 and 2 may be varied. For example, the electrodes which are identified by the reference numbers 8_1, 9_1, 9_2, 8_2 as well as 8_3, 9_3, 9_4, 8_4 in Figures 1 and 2 may alternatively in each case be combined to form one electrode. An electrode which has been combined in this way may be allocated a plurality of tasks by the use of

suitable carrier frequency methods, that is to say the electrode has a read, excitation and compensation function at the same time. The electrodes which are identified by the reference numbers 11_1, 10_1, 10_3 as well as 11_2, 10_2 and 10_4 can also alternatively be combined to form in each case one electrode.

One further possible embodiment of the Coriolis gyro according to the invention and its method of operation will be described in more detail in the following description with reference to Figure 3.

Figure 3 shows the schematic layout of coupled system 1' comprising a first resonator 70_1 and a second resonator 70_2. The first resonator 70_1 is coupled to the second resonator 70_2 via a mechanical coupling element 71, a spring. The first and the second resonator 70_1, 70_2 are formed in a common substrate and can be caused to oscillate in antiphase with respect to one another along a common oscillation axis 72. The first and the second resonator 70_1, 70_2 are identical, and are mapped onto one another via an axis of symmetry 73. The design of the first and of the second resonator 70_1, 70_2 has already been explained in conjunction with Figures 1 and 2, and will therefore not be explained again; identical and mutually corresponding components or component groups are identified by the same reference numbers with identical components which are associated with different resonators being identified by different indexes.

One major difference between the double oscillators shown in Figure 3 and the double oscillators shown in Figures 1 and 2 is that some of the individual electrodes are physically combined to form one overall electrode. For example, the individual electrodes which are identified by the reference numbers 8_1, 8_2, 9_1 and 9_2 in Figure 3 thus form a common electrode. Furthermore, the individual electrodes which are

identified by the reference numbers 8_3, 8_4, 9_3 and 9_4 form a common electrode, and those with the reference numbers 10_4, 10_2, 11_2 as well as the reference numbers 11_1, 10_3 and 10_1 each form an overall electrode. The same applies in an analogous manner to the other double-oscillator system.

During operation of the coupled system 1' according to the invention, the two resonators 70_1, 70_2 oscillate in antiphase along the common oscillation axis 72. The coupled system 1' is thus not susceptible to external disturbances or to disturbances which are emitted by the coupled system 1' itself into the substrate in which the resonators 70_1 and 70_2 are mounted.

When the coupled system 1' is rotated, then the second oscillators 4_1 and 4_2 are deflected in mutually opposite directions (in the X2 direction and in the opposite direction to the X2 direction). When an acceleration of the coupled system 1' occurs, then the second oscillators 4_1, 4_2 are each deflected in the same direction, specifically in the same direction as the acceleration, provided that this acceleration is in the X2 direction, or in the opposite direction to it. Simultaneous or alternating accelerations and rotations can thus be measured.

In principle, it is possible to operate the coupled system 1' on the basis of the evaluation/excitation electronics 2 described in Figures 1 and 2. However, an alternative method (carrier frequency method) is used instead of this in the embodiment shown in Figure 3. This operating method will be described in the following text.

The evaluation/excitation electronics 2 which are identified by the reference number 2' have three control loops: a first control loop for excitation and/or control of an antiphase oscillation of the first

oscillators 3_1 and 3_2 along the common oscillation axis 72, a second control loop for resetting and compensation of the oscillations of the second oscillator 4_1 along the X2 direction, and a control loop for resetting and compensation of the oscillations of the second oscillator 4_2 along the X2 direction. The three described control loops have an amplifier 60, an analog/digital converter 61, a signal separation module 62, a first to third demodulation module 63_1 to 63_3, a control module 64, an electrode voltage calculation module 65, a carrier frequency addition module 67, and a first to sixth digital/analog converter 66_1 to 66_6.

Carrier frequencies can be applied to the electrodes 8_1 to 8_8, 9_1 to 9_8, 10_1 to 10_8 and 11_1 to 11_4 for tapping/excitation (tapping excitation) of the antiphase oscillation or of the oscillations of the second oscillators 4_1, 4_2, in a number of ways: a) using three different frequencies, with one frequency being associated with each control loop, b) using square-wave signals with a time-division multiplexing method, or c) using random phase scrambling (stochastic modulation method). The carrier frequencies are applied to the electrodes 8_1 to 8_8, 9_1 to 9_8, 10_1 to 10_8 and 11_1 to 11_4 via the associated signals UyAo, UyAu (for the second oscillator 4_1) and Uxl, Uxr (for the antiphase resonance of the first oscillators 3_1 to 3_2) as well as UyBu and UyBo (for the second oscillator 4_2), which are produced in the carrier frequency addition module 67 and are excited in antiphase with respect to the above mentioned frequency signals. The oscillations of the first and second oscillators 3_1, 3_2, 4_1 and 4_2 are tapped off via those parts of the gyro frame which are identified by the reference numbers 7_7, 7_9, 7_{11} and 7_{13}, and in this case are additionally used as tapping electrodes, in addition to their function as suspension points for the mass system. For this purpose, the two resonators 70_1, 70_2 are preferably and advantageously designed to be electrically conductive, with all of the

frames, springs and connections. The signal which is tapped off by means of the gyro frame parts 7_7, 7_9, 7_{11} and 7_{13} and is supplied to the amplifier 60 contains information about all three oscillation modes, and is converted by the analog/digital converter 61 to a digital signal which is supplied to the signal separation module 62. The assembled signal is separated in the signal separation module 62 into three different signals: x (which contains information about the antiphase oscillation), yA (which contains information about the deflection of the second oscillator 4_1), as well as yB (which contains information about the deflection of the second oscillator 4_2). The signals are separated differently depending on the type of carrier frequency method used (see a) to c) above), and is carried out by demodulation with the corresponding signal of the carrier frequency method that is used. The signals x, yA and yB are supplied to the demodulation modules 63_1 to 63_3, which demodulate them using an operating frequency of the antiphase oscillation for 0° and 90°. The control module 64 as well as the electrode voltage calculation module 65 for regulation/calculation of the signals Fxl/r or Uxl/r, respectively are preferably configured analogously to the electronics module 2 shown in Figure 1. The control module 64 and the electrode voltage calculation module 65 for regulation/calculation of the signals FyAo/u, UyAo/u, and FyBo/u, UyBo/u are preferably designed analogously to the electronics module 2 shown in Figure 2; the only difference is that the signals for the resetting of the rotation rate and of the quadrature after the multiplication by the operating frequency are passed together with DC voltages for the quadrature auxiliary regulator to a combined electrode pair. The two signals are therefore added, so that the calculation of the electrode voltages includes the resetting signals for the oscillation frequency and the DC signal for the quadrature regulation as well as the frequency tuning. The electrode voltages Uxl/r, UyAo/u

and UyBo/u calculated in this way are then added to the carrier-frequency signals and are passed jointly via the analog/digital converters 66_1 to 66_6 to the electrodes.

Figure 4 shows one preferred embodiment of the control system that is identified by the reference number 64 in Figure 3. The control system 64 has a first to third part 64_1 to 64_3. The first part 64_1 has a first regulator 80, a frequency generator 81, a second regulator 82, an electronics component 83, an addition stage 84 and a multiplier 85. The method of operation of the first part corresponds essentially to the method of operation of the electronics module 2 shown in Figure 1, and will therefore not be described once again here. The second part 64_2 has a first regulator 90, a first modulator 91, a second regulator 92, a second modulator 93 and a third regulator 94. A first and a second addition stage 95, 96 are also provided. A rotation rate signal Ω can be determined at the output of the first regulator 90, and an assembled signal comprising a quadrature bias B_Q and an acceleration A can be determined at the output of the third regulator 94. The third part 64_3 of the control system 64 has a first regulator 100, a first modulator 101, a second regulator 102, a second modulator 103 and a third regulator 104. A first and a second addition stage 105, 106 are also provided. A rotation rate signal Ω with a negative mathematical sign can be tapped off at the output of the first regulator 100, and an assembled signal comprising the quadrature bias B_Q with a negative mathematical sign and an acceleration signal A can be tapped off at the output of the third regulator 104. The method of operation of the second and of the third part 64_2 and 64_3 corresponds to that of the electronics module 2 illustrated in Figure 2, and will therefore not be explained once again here.

The carrier frequency methods described above with antiphase excitation have the advantage that a signal is applied to the amplifier 60 only when the linear oscillators 3_1, 3_2 as well as 4_1 and 4_2 are deflected. The frequency signals which are used for excitation may be discrete frequencies or square-wave signals. Square-wave excitation is preferred, because it is easy to produce and process.

Linear double oscillators are distinguished by particularly high quality owing to the linear movement on the wafer plane. The compensation for the quadrature bias in the case of linear resonators in which at least one oscillator is clamped in at one end can be achieved, according to the invention, globally by adjustment of the orthogonality of the springs. This is achieved by varying the angle of the springs of the oscillator, which is clamped in at one end, by means of a DC voltage, such that the measured quadrature bias B_Q becomes zero. As described above, a corresponding control loop is used for this purpose, which regulates the abovementioned DC voltage such that $B_Q = 0$. This control loop compensates for the quadrature bias at the point of origin, and improves the accuracy of linear oscillation gyros by a number of orders of magnitude.

The linear oscillators of a resonator are preferably each operated at double resonance.